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ONTARIO WATER RESOURCES COMMISSION

CONTROL OF FLOWING ARTESIAN WELLS

DIVISION OF RESEARCH

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CONTROL OF FLOWING ARTESIAN WELLS

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INTRODUCTION

In many areas of Ontario, water supplies are derived almost entirely from ground water. In areas where well water is obtained under flowing artesian conditions, construction failures caused by a lack of knowledge about local ground-water conditions, indifferent well construction practices and failure to attempt to confine the flow within the well casing, are causing the waste of large amounts of usable ground water.

The Ontario Water Resources Commission's Division of Water Resources has been requested on a number of occasions by well owners and other interested parties to advise them on a method to control the leakage of water from flowing artesian wells. The wells in question are less than 200 feet deep and have been completed with a cable-tool rig. When the casing is capped or valved, the water rises to the surface in the annulus around the outside of the casing. Normally, once breakout occurs, water continues to flow from around the casing whether the casing remains capped or not. This can result in extensive head and discharge losses.

Pressure grouting is the method usually required to control problem flowing wells, but it is usually too expensive for the owner.

The Division of Research was asked to investigate the problem of regulating the leakage of water from a well under flowing artesian conditions, and to develop an inexpensive method that would bring the flow under control while retaining the well as a source of supply.

ARTESIAN AQUIFERS

The upper part of the earth's crust is normally porous to some depth. The surface strata, where the openings are only partly filled with water, is called the zone of aeration. Immediately below this, where all the openings are completely filled with water, is the zone of saturation. Geologic formations within a saturated zone that will yield water in usable quantities are called aquifers. If the water within an aquifer is confined above and below by a layer of relatively impervious material and is at the same time supplied laterally from a higher elevation, hydrostatic pressure will develop within the aquifer. The term "artesian" is applied to this condition.

When a well is drilled through the upper confining layer and into an artesian aquifer, water will rise in the well to a level equivalent to the net hydrostatic level. If the elevation of the static water level exceeds ground level elevation, water will flow from the well. A flowing artesian well results.

The type of geologic formation where artesian conditions are found is shown in Figure 1.

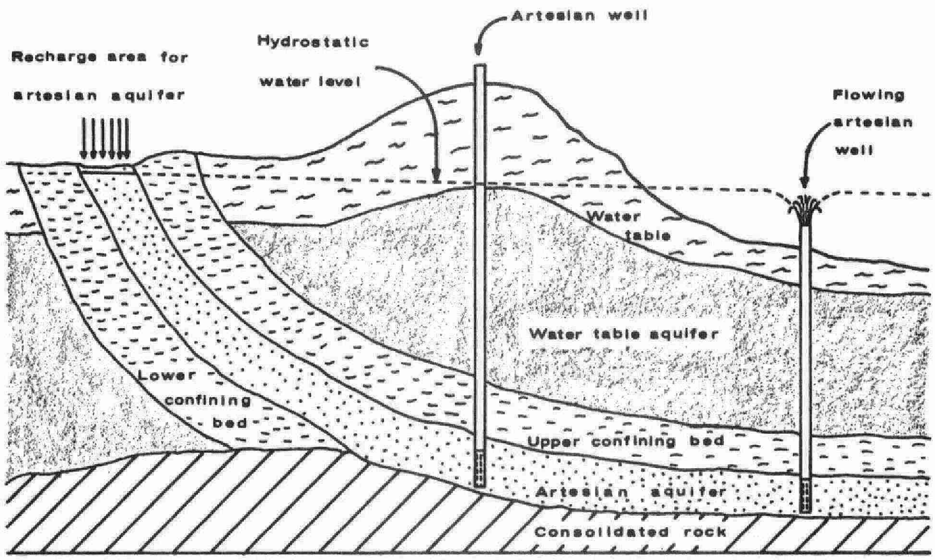

Figure 1. Geologic formation showing classical artesian condition.

CONSTRUCTION OF NEW WELLS

Wells are commonly constructed by any one of the following five methods: digging, jetting, boring, driving or drilling. This study deals largely with drilled wells completed with a cable-tool rig as they are the predominant type found in flowing well areas.

It is difficult to specify the exact method that should be followed in constructing a well. It is not impractical, however, to specify the construction requirements. The AWWA Standard for Deep Wells (1) states that in selecting the type of well to be constructed, the following principles should be borne in mind:

1. The well should be so designed that it will seal off water-bearing formations that are, or may be, contaminated or formations that have undesirable characteristics.

2. The well should be so designed that no opening will be formed between the ground surface and the water-bearing formation other than that through which the water is produced.

3. The materials that are to be a part of the permanent well should be durable.

When a well is projected into an aquifer under flowing artesian conditions, the construction of the well should be such that it will conserve the supply and head by preventing loss of artesian pressure by circulation of water to the surface, to a formation containing no water, or to one containing water under a lower head than that of the aquifer being developed. Also, the construction should be

such that if a flow is developed, it may be kept under control. Such artesian wells may be properly developed in either consolidated or unconsolidated formations (1).

In the construction of flowing wells, the bottom of the protective casing should be sealed into the impervious formation confining the water under artesian head. During the initial drilling operation, for wells drilled with cable-tools, the hole should be carried through the over-burden and at least two feet into the upper confining bed. The casing should then be pulled back about two feet and the exposed section of the hole filled with cement grout. Once the grout has been placed, the casing is then driven to the bottom of the hole. Drilling should not be resumed until the grout has set for at least 72 hours. If quick-setting cement is used, this period may be reduced to 48 hours (4). After the grout has set, drilling into the artesian strata may then be resumed with or without casing protection. When the nature of the impervious confining bed is such that erosion by the flowing water will occur, a casing extending into the artesian aquifer is essential.

MATERIALS FOR GROUTING AND SEALING (1,2,3,5)

Material used for sealing of wells should be of such a character that they can be easily placed, and will assume a permanent and durable form. Normally, Portland cement grout will meet these requirements. Occasionally, however, the use of quick-setting cement will facilitate the well construction project.

The AWWA Standard for Deep Wells specifies that grout shall consist of neat cement mixture with 3 percent bentonite (by volume) and not more than 5½ gallons of water per cubic foot, thereby keeping shrinkage to a minimum.

REHABILITATION OF EXISTING WELLS

The repair of leaking wells is a much more difficult problem than the grouting of a new casing. It is harder yet to find inexpensive methods.

A number of methods are available to control wild flows which occur either during or after a well is drilled. The best method of control depends upon:

1. stratigraphy of the area,
2. depth of the well,
3. design of the well,
4. diameter of the casing,
5. method of construction of the well,
6. pressures and volumes of the flow encountered.

There are three main, different sets of conditions found in the uncontrolled wells under study (6). These are:

(a) a flowing well in over-burden in which there is no casing or from which the casing has been removed.

(b) a flowing well in over-burden with a casing.

(c) a flowing well in bed rock with casing extending to the bedrock surface.

The wells range in depth from 20 to 200 feet. The average ground level flows are from 5 to over 300 gallons per minute, depending upon the general water bearing characteristics of the formation, the diameter of the completed well, and the time of year. With conditions (b) and (c) mentioned earlier, the casing extends into the artesian aquifer and may be screened or open bottom. The diameter of the casings range from 2 inches to over 6 inches.

CASED WELLS

There are several general techniques that have been used successfully in the past to overcome this type of problem.

Grouting of Annular Space - Tremie Method (4, 7)

One method is to reduce the artesian head in the well by pumping the well at a rate sufficient to stop the flow from around the outside of the casing. The annular space surrounding the casing may then be grouted, with care taken not to seal off the aquifer itself. If the annular space is of sufficient size to accommodate a grout pipe* of the required diameter, this is the most satisfactory method for placing the grout. A minimum width of 1½-inch is necessary to accommodate a 3/4-inch coupled minimum-size grout pipe (1). The grout pipe should extend into the upper confining layer initially and should remain submerged in the slurry while the grout is being placed.

To make sure the grout will provide a satisfactory seal, it should be added from the bottom of the space to be grouted toward the surface in one continuous operation. All the required amount of grout should be in place before the initial set occurs. This is to avoid segregation of materials, inclusion of foreign materials or bridging of the grout mixture. Enough grout should be used to fill the annular space to the overflow point. Pumping of the well must continue until the grout has hardened.

* The grout pipe is similar to a tremie pipe commonly used for placing masses of concrete under water.

The main difficulty arising from this approach occurs when the pump draws sand before the flow from around the outside of the casing can be stopped. Sometimes when water is extracted from a formation, its velocity within that formation is sufficient to wash sand from the walls of the hole into the well. Normally the sand particles will settle to the bottom of the well. But if the flow in the well is high enough, the sand may be carried up the well and into the pump. If considerable sand is being pumped with the water, the pump will be subjected to excessive wear. Under severe conditions, it is possible that the pump may sand-lock. When this occurs, an alternative solution should be tried.

Grouting of Annular Space with Asphalt (8)

Asphalt offers a special advantage if, on pumping the well to reduce the static head, the pump draws sand before the flow in the annulus can be stopped. When using cement, the movement of water must first be stopped, as it will wash away the cement and a tight seal will not form. But asphalt is impervious to water even before it sets and if the flow can be reduced it could be used. If the pressure is too great however, breakout will occur around the asphalt as it is applied.

When the heated asphalt is injected through an open-ended pipe and it comes in contact with water, the outer portion begins to harden and form a shell while the inner portion remains fluid. As pumping continues, a number of channels are ruptured in this thin shell, and asphalt trapped outside the initial thin shell also sets to form a fairly thick shell containing a number of open channels. The remainder of the fluid asphalt within the shell is forced out through the open channels as pumping continues. As each succeeding volume of asphalt sets on the outside of a mass already solid, each succeeding asphalt mass is farther and farther from the point where the pipe is located. By controlling the temperature and pressure under which the asphalt is placed, it is possible to block the movement of water in the annulus thereby preventing the loss of water under artesian pressure.

Insertion of Protective Casing (7)

Another method that may be used is to drive an outer casing to the point of refusal over the existing well casing. When the outer casing is being driven, it must extend above the static water level to stop the flow. If this level is too high, it may be lowered by pumping the well. On driving the outer casing, the compaction of the material in the annulus may be sufficient to stop the flow of water outside the inner casing. Cement grout may also be introduced in the annulus here.

With this procedure, care has to be exercised to prevent the outer casing being driven over the well screen, if one has been installed, or having a sand hitch develop between the two strings of pipe that would carry the inner casing along with the outer casing, while being driven. Sometimes an outer casing four to six times the diameter of the original well casing may be required, depending on the size of the original casing and the diameter of the annular space surrounding the well casing.

Modified Casing Method (9, 10)

A fourth method of sealing is a modification of the casing method of grouting in which the slurry is forced down the casing and into the annular space through slots punched in the casing with a mills knife. With this method, a wood plug about the thickness of the inside diameter of the casing is placed in the top of the casing to separate the mud slurry from the water in the casing and the casing capped. The cap has a hole in the center to which a 1½-inch or larger nipple may be attached. A bentonite base mud (12 pounds per gallon or heavier) is pumped through the nipple until mud appears in the annular space around the casing at the ground surface. Pumping is continued, wasting some mud at the ground surface to insure the annular space is completely filled with undiluted mud. This should stop the flow of the well both in the casing and in the annular space outside of the casing.

In wells that have screens installed, the casing is then perforated along its axis for about two feet, at the point where it passes through the impermeable layer. The perforating tool should be inserted and removed slowly, so as to displace as little mud as possible, replacing immediately any mud that is lost.

After removing the perforating tool, a grouting pipe is installed within the casing. Ahrens (9) recommends using a grout pipe constructed in a manner similar to that illustrated in Figure 2. The packers and perforated pipe are run into the hole on standard steel drop-pipe of the same diameter as the perforated pipe, locating and settling the packers at each end of the perforated section of the casing.

The assembly should be run in slowly so as not to displace too much of the mud. A large loss of mud might start the well flowing again.

If the casing is open bottomed, it is not necessary to perforate the casing. Here, one of the packers should be set just within the bottom of the casing and the other in the uncased hole below the casing. Leather or plastic self-sealing cups may be used successfully in casing as packers, but a more positive type of packer is usually required in the uncased hole.

The cement grout is then pumped through the steel drop-pipe displacing the mud upward in the annulus. When the slurry appears in the annular space at the surface, pumping should continue until 1 or 2 cubic feet are wasted at the surface to insure uniform complete filling of the annular space. A measured amount of water is pumped into the drop pipe to displace the cement in it, then the pipe is sealed to keep the slurry in place until it has set. Neat cement grout consisting of 5 gallons of water per sack of cement, to which has been added ½ teaspoon of aluminum powder per sack of cement, should be used with this method (9).

Once the slurry has set, the drop pipe is removed, the packer assembly and cement plug are drilled out and the well bailed clean. To restore the flow, as much mud as possible should be flushed from the hole using clean water and the screened section redeveloped with a surge block. In the unscreened well, the producing zone should be redeveloped with air or another suitable method.

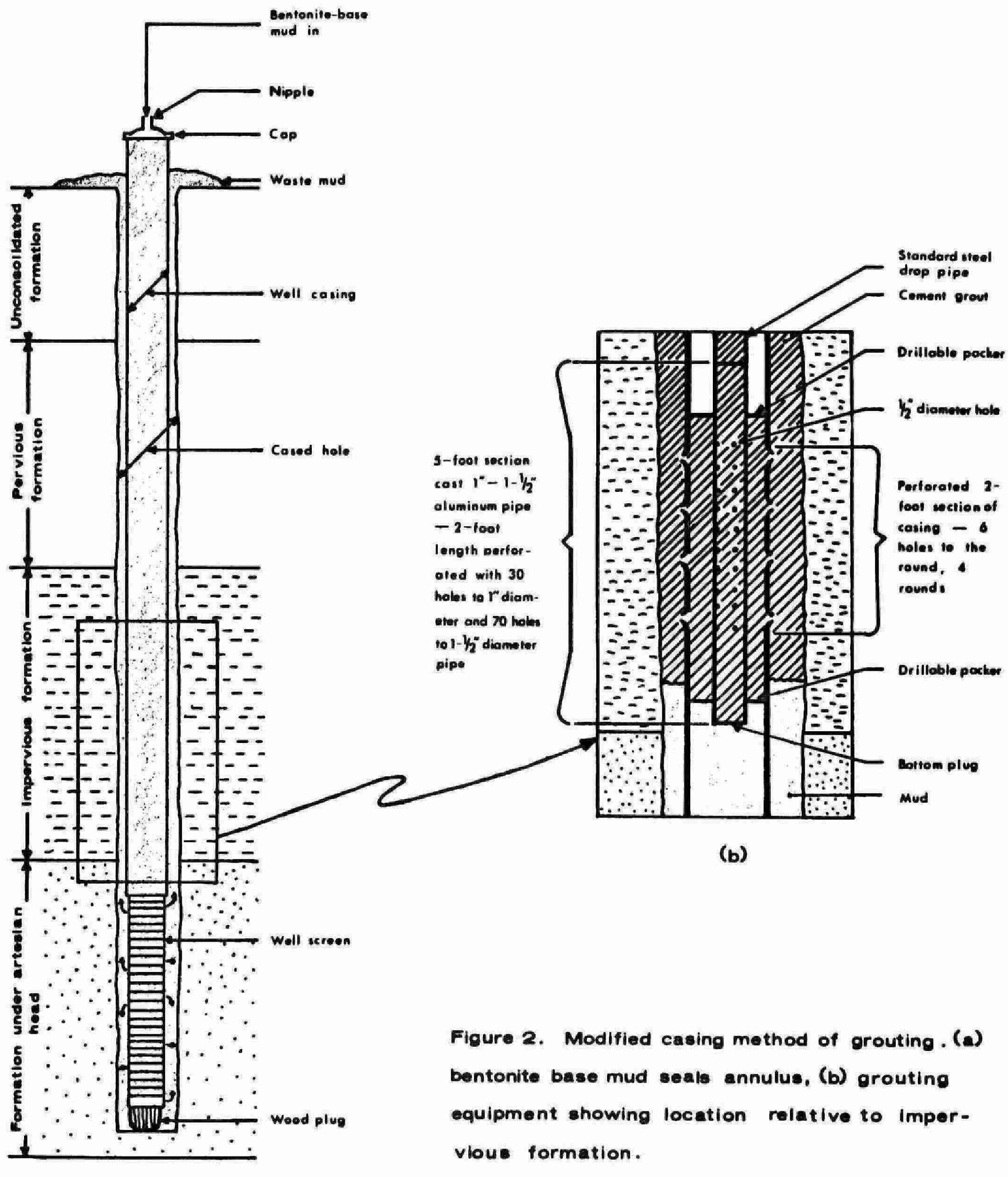

Figure 2. Modified casing method of grouting. (a) bentonite base mud seals annulus, (b) grouting equipment showing location relative to impervious formation.

UNCASED WELLS

The sealing of uncased wells under artesian conditions requires special attention. Frequently, the movement of water between aquifers or to the surface may make sealing by conventional methods impractical. In such wells, a modification of the method recommended in the AWWA Standard for the sealing of abandoned wells with artesian flow could be used.

With this method, a well packer or plug is driven down into the well to the point where the hole passes through the upper confining strata. Once the flow is restricted to the water-bearing formation, a casing of the desired diameter is inserted and grouted in place. When the grout has set, the plug may be drilled out and the well developed using standard methods. A more detailed description of the plugging operation follows in the section on sealing abandoned wells.

Inflatable Packers (11)

A second method called the Fabriform process*, which uses an inflatable packer, appears promising for controlling the flow from uncased wells and for rehabilitating wells from which the casing has been lifted. The packer is a pre-fabricated nylon sleeve made of E. I. Dupont's Cordura nylon. This process, under license in Canada with Intrusion-Prepakt,Limited, is not applicable to permanently cased wells.

If the well is cased, the casing must be pulled then reinserted with the deflated Fabriform bag fastened around the casing at the appropriate depth. The top of the bag is usually located approximately two feet below the top of the upper confining layer. For the uncased well, a casing of operating-well diameter is outfitted then inserted as

* U. S. Patent Nos. 3,396,542 3,396,545 and 3,397,260

outlined above. The nylon form is then pressure-filled with the appropriate grout mixture. Once the flow from around the outside of the well casing has been blocked, the annular space above the packer may be filled with grout or fine sand depending on the material specified.

SEALING ABANDONED WELLS WITH ARTESIAN FLOW

When all attempts at rehabilitation fail, abandonment should be considered. It is important to determine what effect the waste of usable water and energy will have on the yield of the artesian aquifier. The leakage of water from around the casing can wash away large amounts of over-burden from around the well site and can cause drainage problems in low lying areas.

The AWWA Standard for Deep Wells lists "several factors that must be considered to seal an abandoned water well properly:

1. eliminating physical hazard,
2. preventing contamination of ground water,
3. conserving yield and hydrostatic head of aquifers,
4. preventing intermingling of desirable and undesirable waters.

"In sealing wells with artesian flow, large stone aggregate (not more than one-third of the diameter of the hole), lead wool, steel shavings, a well packer, or a wood or cast-lead plug or bridge is used to restrict the flow and thereby permit the placement of sealing material above the formation producing the flow. If preshaped or precast plugs are used, they should be several times longer than the diameter of the well to prevent tilting". The AWWA Standard further recommends that pressure cementing with neat cement be employed.

ECONOMICS

There has been very limited data from which cost information could be developed. Because only a few attempts have been made to control wild flows in the flowing well areas, actual contract cost information was not available. Most of the cost figures presented were derived after consulting well drillers and well contractors experienced with this problem.

An estimate of rehabilitation costs is shown in Table 1. Generally, the total cost of rehabilitation will consist of three separate costs:

1) set-up charge,
2) labour,
3) raw materials.

In the majority of applications, the cost of labour will exceed that of raw materials. Depending on the number of wells contracted and the method(s) used, the set-up charge could be significant.

The cost for one well could vary from $700 to $1,500 depending on the size of the well; the unit cost for a group of ten wells could vary from $520 to $1,100. Examples of the rehabilitation cost estimated for two hypothetical wells are shown in Table 2. These data are general and should only be used as guides.

TABLE 1

ESTIMATED COST FOR REHABILITATING WELLS
UNDER FLOWING ARTESIAN CONDITIONS

	Cost to lift and/or insert casing -	Grouting cost: Standard Methods (c)	Grouting cost: Pressure (d)	Fabriform Process (e)
Set-up charge (a) cost per well	$0 - 200.00	$0 - 200.00	$200.00 - 500.00	$500.00
Labour cost (b) per hour	20.00-25.00	20.00 - 25.00	25.00 - 50.00	50.00

RAW MATERIAL COST

Casing diameter (outer)	7	8	10	12
Cost per foot	$4.00	$5.00	$7.00	$9.00

Grouting material	Cost per cubic foot
Cementatious grout	$0.70 - 1.50
Asphalt cement	2.30
Impact grout	4.00 - 5.00
Chemical grout	10.00

(a) Most well drillers or well contractors stipulate a basic set-up charge to bring in their men and equipment. Depending on their location relative to the work area and also depending on the number of jobs included in a contract, this cost could vary from a nominal charge of $20 per well or less for a group of 10 wells or more to as high as $500 per well.

Normally the well driller will specify only one set-up charge no matter how many separate operations he undertakes at that well.

(b) Time estimates indicate it could take from one to two or more working days to rehabilitate one well. The time required will depend on several factors including the size and condition of the well, the artesian pressures encountered, and the number of operations used.

(c) The standard methods for grouting include dump bailer, casing and tremie methods.

(d) Pressure grouting procedures are highly technical requiring men of skill and mechanical training. Few well drillers are properly equipped to do this type of work and would have to employ a sub-contractor. A second set-up charge could be involved.

(e) Intrusion-Prepakt, Limited, who hold the Canadian license for the Fabriform process, is not equipped to lift or inset well casing. Again, this could involve another set-up charge.

(f) Raw material costs are approximate and could vary depending on supply and use factors.

TABLE 2

APPROXIMATE REHABILITATION COSTS FOR TWO HYPOTHETICAL FLOWING ARTESIAN WELLS

	Protective casing method including grouting	Fabriform process
Set-up charge	$200.00	1. Lift and re-insert casing $200.00 2. Fabriform process 500.00
Total Cost	$200.00	$700.00
Time required, hrs	16	8 + 8
Labour, cost/hr	$22.50	8 hrs at $22.50/hr 8 hrs at 50.00/hr
Total Cost	360.00	580.00
Raw materials		
Casing, ft.	30	0
Cost/ft.	$7.00	-
Casing cost	$210.00	-
Grout, cu ft	18	30
Cost/cu ft	$4.00	$4.00
Grout cost	$72.00	$120.00
Total Material Cost	$282.00	$120.00
Estimated Cost		
Set-up	$200.00	$700.00
Labour	360.00	580.00
Materials	282.00	120.00
Rehabilitation Cost	$842.00	$1,400.00

DISCUSSION

It appears that the methods available for controlling the leakage of water from flowing artesian wells are well developed; most of them have been used successfully in the past to control wild flows. Nevertheless, while they should cost less than drilling a new well, they are expensive.

In addition to the methods discussed, chemical grouting may also be used to control wild flows. The grouting techniques however, are relatively complex. The equipment and labour costs are similar to pressure grouting costs and are generally higher than those shown for the methods discussed earlier. Also, the chemical grouts are more expensive than either cement grout or impact (fast set) grout (Table 1). Compared to other methods available, chemical grouting is not economically practical.

In almost every area where problem wells are experienced, the hydrostatic water level is decreasing and there is concern that the flowing properties may be lost. This means not only an increase in the cost of supplying water, but also a loss of usable ground water. This loss is in some degree due to construction failure caused by lack of cementation or improper sealing and can be eliminated. Whether this is practical, however, will depend primarily on cost.

In the future, when constructing new wells under artesian conditions, the annular space between the casing and the wall of the hole should be filled with grout, according to one of the methods outlined in AWWA Standard for Deep Wells, Section 1-5, and A1-8 Grouting and Sealing. One method recommended is outlined in the section, Construction of New

Wells. After the grout has set, the well may be drilled into the artesian strata and a telescoping screen run in and set in the producing horizon, after which the well should be developed.

Where the conservation of ground water is desired, the problem wells should be restored. The Ontario Water Resources Commission has the supervision of all surface and ground waters in Ontario used as a source of water supply. (The Ontario Water Resources Commission Act, S.26-1) Where the flowing or leaking of water from a well interferes, in the opinion of the Commission, with any public or private interest in the water, the Commission may require the person who constructed or made the well, or the registered owner of the land in which the well is located, to stop or regulate the flowing or leaking water. S.28a-(5) Using this section, direction could be given to restore problem wells.

No matter what the method used, its success will depend largely on the accuracy of the water well record. The exact depth and extent of the impervious confining layer, the depth of the water bearing zone and the length of casing must all be known if any of the methods outlined are used.

Because this problem is widespread in Ontario, work will continue on an experimental basis to develop a simpler method for controlling wild flows.

CONCLUSIONS

The following conclusions are presented in respect to the foregoing study:

1. There does not seem to be a simple and inexpensive method to control problem flowing wells.

2. The most economical solution to this problem will have to be applied when the well is being constructed.

3. Several methods are available that have been used successfully to control wild flows. This is not a simple matter however, and generally they are expensive.

4. New legislation is required for controlling the construction of new wells under artesian conditions.

RECOMMENDATIONS

The following recommendations are presented as a result of this study:

1. New legislation should be enacted concerning the construction of new wells under artesian conditions. The legislation should specify construction requirements for new wells under artesian conditions and outline the responsibilities of the well contractor and the well owner. The AWWA Standard for Deep Wells and the USPHS Model Water Well Law could be used as guides.

2. Each problem well should be reviewed to determine whether rehabilitation or abandonment is required. Present legislative authority is available to direct the person(s) concerned to proceed accordingly.

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